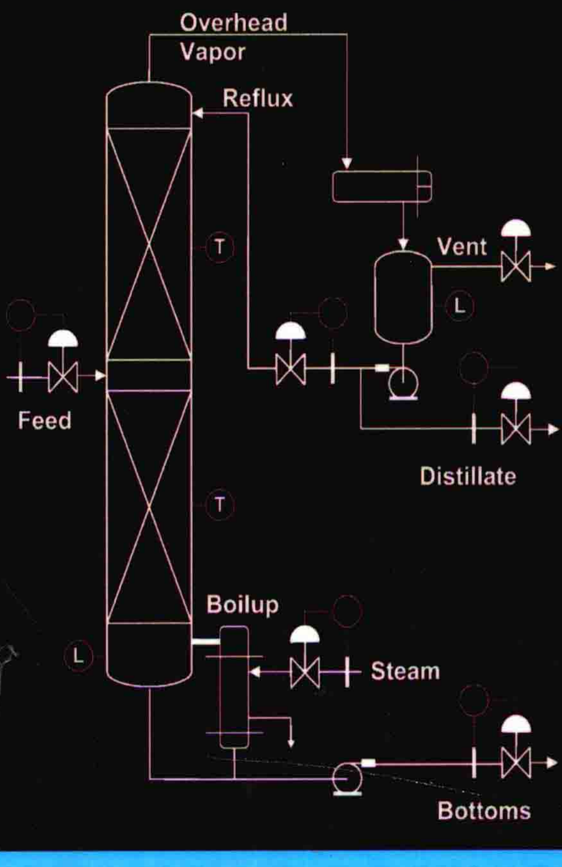
DISTILLATION CONTROL, OPTIMIZATION, AND TUNING

Fundamentals and Strategies



LANNY ROBBINS

CRC Press
Taylor & Francis Group

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Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-5748-9 (Hardback)

Library of Congress Cataloging-in-Publication Data

Robbins, Lanny.
Distillation control, optimization, and tuning : fundamentals and strategies / Lanny Robbins.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-4398-5748-9 (hardback)
1. Distillation. 2. Separation (Technology) I. Title.

TP156.D5R625 2011
660'.28425--dc22 2010048806

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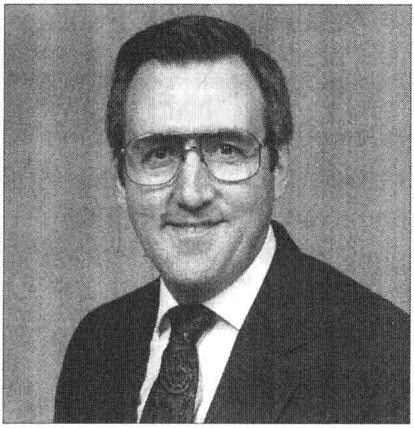
The Author



Dr. Lanny Robbins, president of Larco Technologies LLC, is a consultant. He retired with the title of Research Fellow after 37 years at The Dow Chemical Company at Midland, Michigan. In 2006 Dr. Robbins was elected to the National Academy of Engineering. He also received the Marston Medal, which is the top honor awarded by the Department of Engineering, Iowa State University. His expertise is in fundamental chemical engineering research and pilot plant process development, especially for separation and purification processes. He has developed unique technology for scale-down and scientific study of plant processes to generate experimental data for successful scale-up. He is the author of the liquid–liquid extraction chapters in *Perry's Chemical Engineer's Handbook*, sixth and seventh editions, and *Schweitzer's Handbook of Separation Techniques for Chemical Engineers*, first through third editions. Robbins has researched, developed, and implemented many separation and purification unit operations used at Dow.

Dr. Robbins is an inventor of two new liquid distributor designs for packed distillation, absorption, and stripping towers that are used in over 450 towers. Robbins developed a number of liquid–liquid extraction processes for product recovery and for process water purification. He developed the AquaDetox aqueous purification device and design technology for stripping residual solvents and impurities from water to the parts-per-billion range. He also developed other commercial wastewater purification technology to reduce trace impurities to unprecedented low levels of parts-per-quadrillion. Robbins developed the Sorbathene pressure swing adsorption process to remove hydrocarbons, solvents, and monomers from vent emissions. Robbins is the author of 19 publications, 18 U.S. patents, and more than 185 technical reports for Dow.

Dr. Robbins has served as an adjunct professor at Virginia Polytechnic Institute and Michigan State University. Robbins received the prestigious H. H. Dow Gold Medal from the board of directors of The Dow Chemical Company in 1993, and in 2003 he received the inaugural award for the Process Development Division of the national American Institute of Chemical Engineers (AIChE). Dr. Robbins received his B.S., M.S., and Ph.D. degrees in chemical engineering from Iowa State University.

Contents

Chapter 1

Introduction and Overview

Welcome to the *Strategy of Distillation Control, Optimizing Quality Performance, and Tuning Control Loops*. This first chapter is a short summary of the topics covered in this course.

Learning Objectives

When you have completed this chapter, you should be able to

1. Understand the general organization of the content in the course
2. Know the course objectives
3. Know how to proceed through the course

1.1 Course Coverage

This book focuses on the fundamentals of process control of distillation columns. It covers the following topics:

1. The process variables for continuous binary distillation columns and four basic control strategies
2. The distillate and bottoms product quality performance objectives
3. The tuning of process control loops

When you finish this course, you will understand the fundamental separation and purification concepts to be achieved by a distillation column and the functional criteria that are critical for successful implementation of process control. Concepts for measuring and optimizing product quality performance will also be understood. You will also learn how process control loops for distillation columns can be tuned for stable operation with a balance between minimum variability from setpoint changes and excellent response to load disturbances. By approaching the subject this way, you will gain a fundamental understanding that can guide decisions for the design, operation, and troubleshooting of distillation process control systems.

This book is written from a perspective that was developed as the result of 37 years of industrial research at The Dow Chemical Company that focused on inventing, developing, and implementing industrial separation and purification processes. The work process for research and development is the scientific method, which will now be described.

The Scientific Method

1. Define the problem and the opportunity.
2. Search and understand the state of the art.
3. Develop a hypothesis, that is, a concept or a model.
4. Design and run experiments to test the validity of the hypothesis.
5. Evaluate, summarize, and document the results.

The main problem in distillation process control is to separate and purify chemical components in liquid and vapor streams while shedding the disturbances that are imposed on the distillation column. The opportunity is to separate the components from a feed stream into new vapor and liquid streams that have increased economic value at a cost that is competitive with other producers. Conducting research in a large corporation provides the opportunity to apply the results of improved performance to many distillation towers in many different businesses.

Distillation is a mature technology that is well developed and tested by the scientific method. Two comprehensive books have been written by Kister[1,2] on the design and operation of distillation columns. The control of distillation columns has been widely studied for many years, many papers have been written, and several books have been published on the subject such as the one by Buckley, Luyben, and Shunta.[3] There is a large body of information to search and understand in the state of the art of distillation and process control.

During the last 20 years, there has been a continuing emphasis on improved product quality, performance, and reduced operating costs such as energy consumption, lost product, rework, maintenance, and labor cost per unit of product produced. Computer hardware and computer programs have been improved dramatically for simulating and modeling the distillation process and the dynamic response for the hypothesis in Step 3 in the scientific method. The chemical engineering fundamentals and mathematical hypotheses used to describe the design and performance of distillation columns are continually tested for their validity by plant operations in industry. Ultimately, the results are judged by the business that is responsible for the quality and profitability of the products produced by distillation and by the manufacturing department responsible for operating the process equipment.

1.2 Purpose

The purpose of this book is to present the fundamentals of process control of a distillation column as a separation and purification unit operation. This includes the critical concepts and functional criteria for the design, operation, and troubleshooting of distillation process control plus the concepts of measuring and improving product quality performance. There is a prevailing need to strike a balance between understanding the concepts that are critical to exercising good engineering judgment and understanding the intricate details of each hypothesis. The focus of this book is on achieving distillation product purity at low cost without dwelling on complex mathematical descriptions.

Often, there is more than one way to achieve the desired results, so conflicts can develop about which is the best way to approach a subject and what creates the most value. The cost of acquiring resources and developing everyone's knowledge is generally too high. On the other hand, the risk of failing to meet production rates or product quality or of consuming excessive raw materials and energy has economic consequences for the business. Generally, the highest value is created by striking a balance.

1.3 Audience and Prerequisites

The material in this book can be useful for engineers, technicians, and plant operators concerned with the design, operation, and troubleshooting of process control systems for distillation columns. The course can also be useful for students who want to gain insights into the practical approach to distillation process control in industry and tuning control loops in a plant control room.

There are no specific prerequisites for taking this course. However, it would be helpful to have a basic understanding of the distillation unit operation and process control loop concepts. The only mathematics skills required are basic arithmetic and algebra.

1.4 Study Materials

This textbook is the only study material required. Additional references are provided in each chapter.

1.5 Organization and Sequence

This book is divided into 10 separate study chapters. Chapters 2, 3, and 4 deal with the distillation variables, and Chapter 5 covers distillation process control strategies. Chapter 6 describes some of the constraints on distillation variables and separation capabilities. Chapter 7 introduces the concepts that are critical to product quality and the measurements that evaluate performance criteria such as frequency of failure. Chapter 8 describes the concepts and nomenclature that are fundamental to PID control loops. Chapter 9 covers the concepts of tuning process controllers when they are operating in automatic output mode. Chapter 10 is about measuring the response of process variables when the controller is in manual output mode, that is, with no feedback from the process variable.

There are example problems and exercises for each chapter to test your understanding of the material. The solutions to all of the exercises are given in the appendix.

1.6 Course Objectives

When you have completed this entire book, you should be able to

1. Understand the manipulated variables and controlled variables for a distillation column
2. Understand the fundamentals of various strategies for controlling distillation columns
3. Understand many of the constraints and limits that cannot be exceeded in distillation control
4. Understand the measurements that are critical to product quality performance and the resultant frequency of failure
5. Understand how to tune a process controller when it is in automatic output mode and how to demonstrate the response of a process with the controller in manual output mode

1.7 Course Length

The organization of this book into chapters is designed for either classroom teaching or self-paced learning that can meet the needs and skill level of each student. Chapter 2 is helpful for understanding the nomenclature used throughout the book regarding the naming conventions for the distillation process streams. Chapter 7 can be studied alone for understanding the optimization of product quality performance and the frequency of failure. Chapters 9 and 10 can be studied separately for tuning control loops.

References

1. Kister, H. Z., *Distillation Operation*, McGraw-Hill, New York, 1989.
2. Kister, H. Z., *Distillation Design*, McGraw-Hill, New York, 1992.
3. Buckley, P. S., Luyben, W. L., and Shunta, J. P., *Design of Distillation Column Control Systems*, ISA, Research Triangle Park, North Carolina, 1985.

Chapter 2

Distillation Control Variables

This chapter provides you with a concept drawing of a distillation column with all of the streams labeled.

Learning Objectives

When you have completed this chapter, you should be able to

1. Use the distillation column concept drawing for reference and for communication with others about the key variables and control elements
2. Recognize the names of the inlet and outlet streams used in a distillation system
3. Know the standard definition of reflux ratio

Distillation is the main unit operation in chemical engineering for the separation and purification of liquids and vapors. A feed mixture of chemicals can be separated into the more